**Naval Research Laboratory**

Washington, DC 20375-5320

# An Initial Evaluation of Video-based Fire Detection Technologies

DANIEL T. GOTTUK
MATTHEW HARRISON
JOSEPH L. SCHEFFEY

*Hughes Associates, Inc.*
*Baltimore, MD*


SUSAN L. ROSE-PEHRSSON

*Chemical Dynamics and Diagnostics Branch*
*Chemistry Division*


FREDERICK W. WILLIAMS
JOHN P. FARLEY

*Navy Technology Center for Safety and Survivability*
*Chemistry Division*

January 9, 2004

# REPORT DOCUMENTATION PAGE

| 1. REPORT DATE (DD-MM-YYYY) | 2. REPORT TYPE | 3. DATES COVERED (From - To) |
|---|---|---|
| January 9, 2004 | Memorandum Report | |

**4. TITLE AND SUBTITLE**

An Initial Evaluation of Video-based Fire Detection Technologies

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**

Daniel T. Gottuk,* Matthew Harrison,* Joseph L. Schieffey,* Susan L. Rose-Pehrsson,† John P. Farley, and Frederick W. Williams

**5d. PROJECT NUMBER**
61-8244-0-3-5

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

Naval Research Laboratory, Code 6180
4555 Overlook Avenue, SW
Washington, DC 20375-5320

**8. PERFORMING ORGANIZATION REPORT NUMBER**

NRL/MR/6180--04-8737

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

**10. SPONSOR / MONITOR'S ACRONYM(S)**

**11. SPONSOR / MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION / AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

*Hughes Associates, Inc., Baltimore, MD
†Chemical Dynamics and Diagnostics Branch, Chemistry Division

**14. ABSTRACT**

Computer processing and image analysis technologies have improved significantly to allow the recent development of effective video-based fire detection systems. Currently, smoke detection algorithms are the most mature. Typically, these systems are being designed and used in large facilities, outdoor locations, and tunnels. However, the technologies are also expected, with some modifications, to be effective in smaller, cluttered compartments found on ships. With the move to use onboard video surveillance, there are advantages in using the video images for other functions, such as fire detection. The video-based recognition technology also has future potential for personnel tracking, flooding detection, and physical damage assessment onboard ship as more event recognition algorithms are developed. This work represents the initial evaluation of video-based detection technologies for improved situations awareness and damage control assessment onboard Navy ships. The test results indicate that the video-based detection systems using smoke alarm algorithms can provide comparable to better fire detection than point-type smoke detectors.

**15. SUBJECT TERMS**

Damage control; Fire detections; Machine vision

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| **a. REPORT** | **b. ABSTRACT** | **c. THIS PAGE** | UL | 54 | Frederick W. Williams |
| Unclassified | Unclassified | Unclassified | | | **19b. TELEPHONE NUMBER** (include area code) 202-767-2476 |

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

CONTENTS

        (See attached Disc)

ii

# 1.0     INTRODUCTION

The Advanced Damage Countermeasures program seeks to develop and demonstrate improved Damage Control (DC) capabilities to include anticipatory DC response mechanisms to help ensure CVNX and the DD(X) family of ships recoverability performance goals can be met with established manning level and systems.  An important element of the ADC Program is the development of a volume sensor system that can assess damage conditions within a space without relying on a point source measurement.  This work represents the second step in assessing potential technologies that may be used in developing a volume sensor system.  The first step (FY01 work) consisted of a literature review and an industry review of current and emerging technologies [1].  Based on the FY01 work, several technologies were identified that have potential for meeting objectives of the volume sensor development effort.

The objective of the volume sensor work is to develop an affordable, real-time sensor system for identification of shipboard conditions, such as fire, explosion, flooding and security monitoring of spaces.  The system should have improved sensitivity and event discrimination above that of point detectors (i.e., a device that senses at a specific point location) and should provide better nuisance alarm immunity than conventional detectors (e.g., smoke detectors).  This work represents the first phase of a multi-year program, part of which is to identify, evaluate and adapt video-based detection technologies for improved situation awareness and damage control assessment onboard Navy ships.  Specifically, the FY02 study focused on evaluating video-based systems designed to detect fires.  The technologies and systems evaluated have the potential for providing detection of other shipboard conditions.  These applications will be investigated in subsequent years.

# 2.0     OBJECTIVE

The objective of this study was to experimentally evaluate the fire detection and nuisance alarm immunity performance of two commercially available, video-based fire detection systems.  An additional goal was to gain a general assessment of the technology, particularly as it would be used onboard ship.

# 3.0     TECHNICAL APPROACH

The approach was to expose sets of different video-based and point-type fire detector technologies to varying fire and nuisance sources in a simulated shipboard space.  The performance of the video-based fire detection systems was compared to the performance of the

state-of-the-art smoke detection systems.  Performance was evaluated based on the ability of the system to detect small and incipient fires and to reject potential nuisance sources.  The comparative response times between the video-based and point-type smoke detectors were also used as a measure of performance.


## 4.0 EXPERIMENTAL SETUP AND PROCEDURE


### 4.1 Test Compartment

The tests were conducted in a 10 x 10 x 3 m high (33 x 33 x 10 ft) compartment located in the Baltimore Laboratories of Hughes Associates.  Fig. 1 shows a layout of the test compartment and instrumentation.  Lighting in the space was provided by eleven 1.2 m (4 ft) long fluorescent light fixtures, each with four 34 W bulbs.  Additional light was supplied from the lab through two large observation windows, measuring 1.2 m x 1.4 m, located on each of three sides of the test space.

Multiple structures were installed in the space to provide visual obstructions, similar to electrical cabinets, lockers and bunks.  The obstructions were fabricated using metal studs and Masonite board, which had a brown, low-reflective finish.  The overall dimensions of the obstructions were 0.6 x 2.4 x 2.4 m high (2 x 8 x 8 ft).  Fig. 1 shows the layout of the obstructions, intended to provide a fairly cluttered area on one side of the space and an open area on the other side of the space.  Another obstruction included in the test compartment was a cable tray that spanned 4.6 m (15 ft) across the overhead, approximately 0.3 m (1 ft) below.  Figs. 2 to 4 show photographs of the space and obstructions from the perspective of the three cameras depicted in Fig. 1.

The test space was cleared of smoke between tests via a 0.54 x 0.54 m (21 x 21 in)vent and exhaust fan system.  The exhaust vent was located in the overhead near Camera 3, as shown in Fig. 1.  The exhaust rate provided 14 air changes per hour.  Except for two tests (11 and 12), there was no ventilation during the tests.  During Tests 11 and 12, the ventilation was set to provide 10 air changes per hour and the two doors to the test space were opened.

The test compartment was located in a working laboratory/warehouse facility.  The laboratory was indirectly conditioned by the adjoining office space and was also frequently opened to the outside via rollup delivery doors.  Conditions ranged from about 21 to 32 ºC with typical temperatures around 27 ºC.
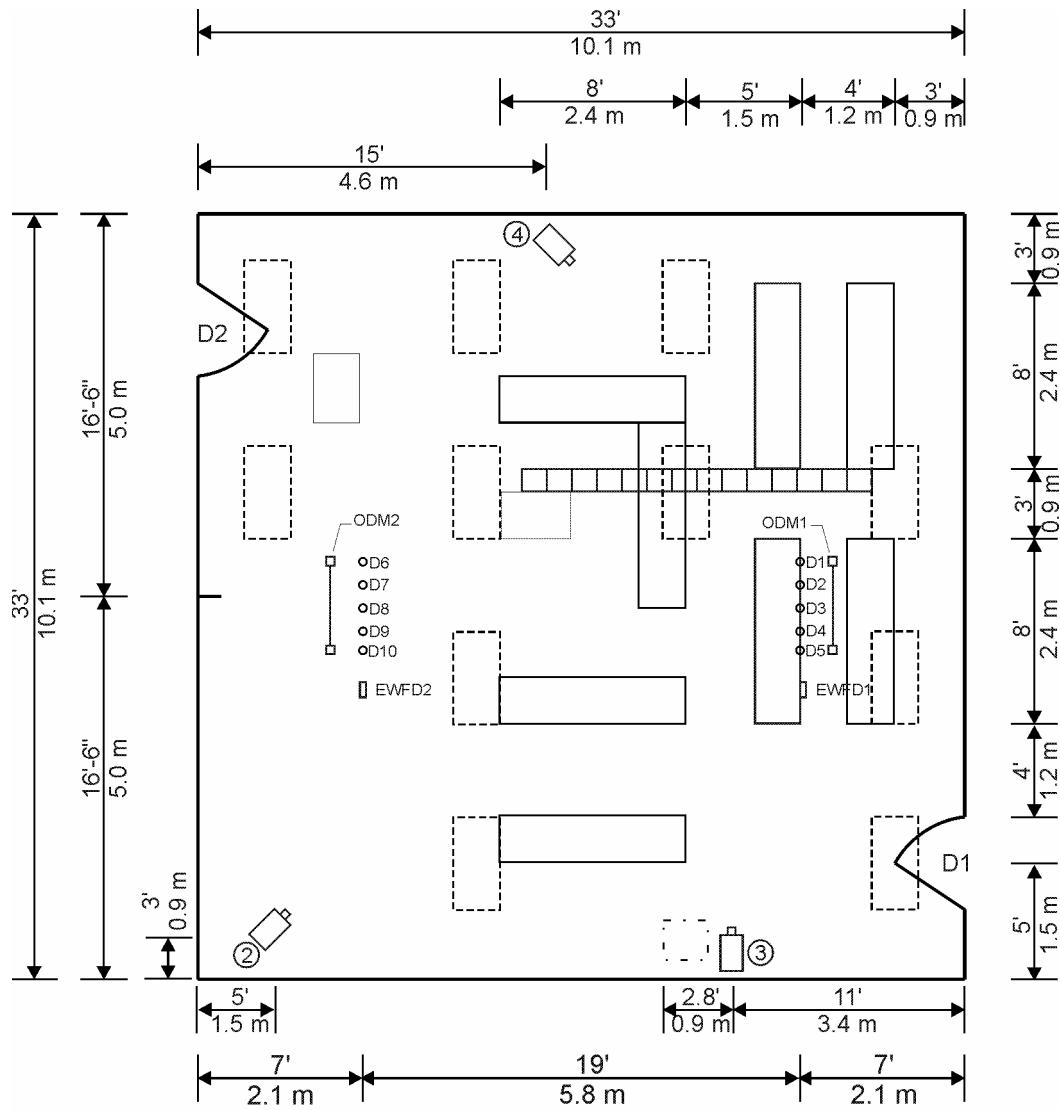
**Fig. 1. – Schematic of experimental setup**

Legend:

- Cabinet/bunks (2' x 8' x 8' high)
- Overhead lighting (2' x 4')
- Cable tray in overhead
- Exhaust vent in overhead (1.8' x 1.8')
- Camera (8" below overhead)
- Smoke detector (1' spacing)
- ODM (1' from detectors)

**Fig. 2. – Photo from Camera 2 of open area in test space**



**Fig. 3. – Photo from Camera 3 looking down corridor between cabinet obstructions**



**Fig. 4. – Photo from Camera 4 across the overhead above the cabinet obstructions**

## 4.2    Instrumentation

Two identical sets of smoke detectors were located 5.8 m (19 ft) apart, which represents an equal coverage of the space by two detectors based on the industry standard spacing of 84 m$^2$ (900 ft$^2$) per unit.  The instrumentation utilized is presented in Table 1 and the locations of equipment are shown in Fig. 1.  The smoke detectors were spaced 0.3 m (1 ft) on center.  The optical density meters (ODM) had a 1.52 m (5 ft) path length and were positioned parallel to the line of smoke detectors, 0.3 m (1 ft) away.

Three cameras were located in the compartment to provide an overall view of the test space.  The images obtained are shown in Figs. 2 to 4.  The number of cameras and locations were determined with input from the video-based fire alarm system manufacturers.  The camera views do not necessarily represent the optimum placement.  Rather, the cameras were setup to provide a range of views that also covered the entire test area.  Camera 2 provides a view of the open area, Camera 3 provides a view down a corridor between the cabinet obstructions, and Camera 4 provides a view of the overhead, across the top of multiple cabinet obstructions.  The cable tray also traverses the image of Camera 4.  Actual ship spaces can be much more cluttered in the overhead with cables, ventilation ductwork, light fixtures, and beams.  The optimum number of cameras and placement onboard ship will need to account for all these visual obstructions.  Future work will evaluate the placement issue and take into account other factors, such as the need for images that provide acceptable video surveillance.

### Table 1. – Instrumentation

| Manufacturer | Model Number | ID on Fig. 1 | Description |
|---|---|---|---|
| Fire Sentry | VSD-8 | Cameras 2-4 | Video smoke detection system |
| Fastcom | Smoke & Fire Alert (SFA) | Cameras 2-4 | Video fire and smoke detection system |
| Simplex | 4098-9717 | D1 & D6 | Ionization smoke detector |
|  | 4098-9714 | D2 & D7 | Photoelectric smoke detector |
| Notifier | SDX-751 | D3 & D8 | Photoelectric smoke detector |
|  | FSI-751 | D2 & D7 | Ionization smoke detector |
|  | LPX-751 |  | View (laser based photoelectric) |

4.2.1   *Smoke Detectors*

Two commercial smoke detection systems were used to provide a benchmark of state-of-the-art, point-type fire alarm equipment.  The Simplex photoelectric and ionization smoke detectors were powered and monitored with a specially designed hardware/software package which polled the detectors every 4 to 5 seconds and saved the data to a computer file.  This system allowed the smoke detectors to be evaluated via post-test processing at any sensitivity alarm level within their operating ranges.  For this study, the Simplex detector response times were evaluated at an alarm sensitivity of 7.7%/m (2.4%/ft) for the photoelectric units and 4.2%/m (1.3%/ft) for the ionization units.

The Notifier system detectors were controlled using an AFP 400 panel.  The panel was configured using the Notifier Veri•Fire 400$^{TM}$ Programming Utility, which allowed programs to be edited, downloaded and uploaded from a personal computer.  A manufacturer modified version of the panel software was utilized to allow the history file to record event times to the nearest second (typical panel operation only records times to the nearest minute) [2].  The Notifier panel recorded alarm responses for "pre-alarm" and "alarm" sensitivity levels.  These levels are preset with the software to one of nine selectable values corresponding to the specific range of each detector type.  Table 2 presents the alarm levels used for the Notifier smoke detectors.

**Table 2. – Notifier Alarm Sensitivity Settings in % obscuration/m (%/ft)**

| Detector | Pre-Alarm Level | Alarm Level |
|---|---|---|
| Photoelectric | 3.2 (1.0) | 7.7 (2.4) |
| Ionization | 4.2 (1.3) | 5.8 (1.8) |
| VIEW | 1.6 (0.5) | 3.2 (1.0) |

4.2.2   *Video-based Fire Detection Systems*

Two video-based fire detection systems were evaluated.  Each system was operated from an independent personal computer.  The Smoke and Fire Alert (SFA) system was installed by Fastcom on a standard Dell DIM 4300 Pentium 4 PC running Windows 2000.  The VSD-8 system came installed from Fire Sentry on a proprietary PC running DOS.  Both systems were setup by manufacturer personnel.  Due to scheduling and logistical constraints, the manufacturers were unable to make adjustments to the systems after testing commenced.  In an actual installation, there would be a period of time during which the system operates, data is logged and the manufacturer would then make adjustments to fine-tune the system for the environment.

Both systems used the same three cameras located in the test space (see Fig. 1).  The video images were obtained using standard CCD color cameras (Sony, SCS-DC14) with Pentex manual iris 3.5 - 8 mm, variable focus lens (total cost ~$250).  Using a siamese cable (RG59 coax for video together with 18/2 for power), each video image was transmitted to an electronic

distribution amplifier (Kramer Electronics, 105VB), which split the signal to three destinations: 1) the SFA video detection system, 2) the VSD video detection system, and 3) a VCR, preceded by a time-date generator. All video cable connections were made with BNC connectors.

Both video-based fire detection systems included hardware and software to provide outputs corresponding to alarm conditions. The outputs of all alarm conditions were monitored by a data acquisition system that also recorded the output from the optical density meters, which measured the smoke levels at each location of smoke detectors. The data acquisition system consisted of Keithley Metrabyte data acquisition hardware (DAS 8 I/O card and EXP 16 screw terminal board) and LabTech Notebook software on a PC. Data was collected every second. The output file included a column of data for each camera and video based detection system (e.g., VSD camera 2 and SFA camera 2). Alarms were indicated by a step change in the output value for each system per camera. Both video-based systems maintained an electronic history file of all alarms. Each alarm entry was accompanied by a digital photo showing the video image causing the alarm condition. The SFA system monitored and logged pre-alarm and alarm conditions. The VSD-8 system was set up to only log alarm conditions; however, both pre-alarm and alarm levels can be set and trigger outputs.

The following information in this section provides details of the two video-based fire detection systems. The VSD-8 system is sold in the U.S. by Fire Sentry and was developed by ISL in the United Kingdom. The system has been installed in some applications for over 5 years (e.g., electric power stations).

Using the image from a video camera, the VSD-8 identifies small areas of change within the image (zone) at the digitization stage. Only the pixels associated with the area of change are passed on to a series of software filters that look for particular characteristics associated with smoke. Additional analysis is conducted on the filtered characteristics to determine if all alarm conditions have been met.

The VSD-8 system has a graphical user interface (GUI) that provides a black and white display. The GUI displays the current status of the system and allows the user to display one view at a time for active detection mode and to examine the history log of recorded alarms (each alarm event includes a snapshot image). The GUI also allows the user to configure the system. The GUI is easy to use and the image resolution on the screen is fair. Further developments are on-going with the GUI.

The SFA video-based fire alarm system is manufactured by Fastcom in Switzerland and has been introduced in the past few years. Systems have or are being evaluated for applications in tunnels, offshore oilrig platforms, and large nuclear research facilities.

Fastcom uses the terms smoke and fire alarms, where fire refers to flaming fires. The fire algorithms detect fire based on dynamic characteristics without using a reference image. This methodology allows the system to be used with zoom, pan and tilt cameras. The smoke alarm algorithm uses a reference image to determine if a smoky condition develops. The smoke and fire alarm levels are dependent on factors such as the size, activity, speed of development and

7

dynamic behavior of the smoke or flame.  The system has primarily been designed for environments with controlled lighting conditions.

The SFA Graphical User Interface (GUI) displays the current status of the system and allows the user to examine the history log of recorded alarms, pre-alarms, trouble and supervisory signals.  The GUI also allows the user to configure the system.  An example snapshot of the GUI display is shown in Fig. 5.  The GUI is a Windows-based application that displays color images.  The main display screen shows thumbnail images of all 8 cameras and two larger images of user-selected cameras.  The GUI is easily navigated.  All alarms, pre-alarms, trouble
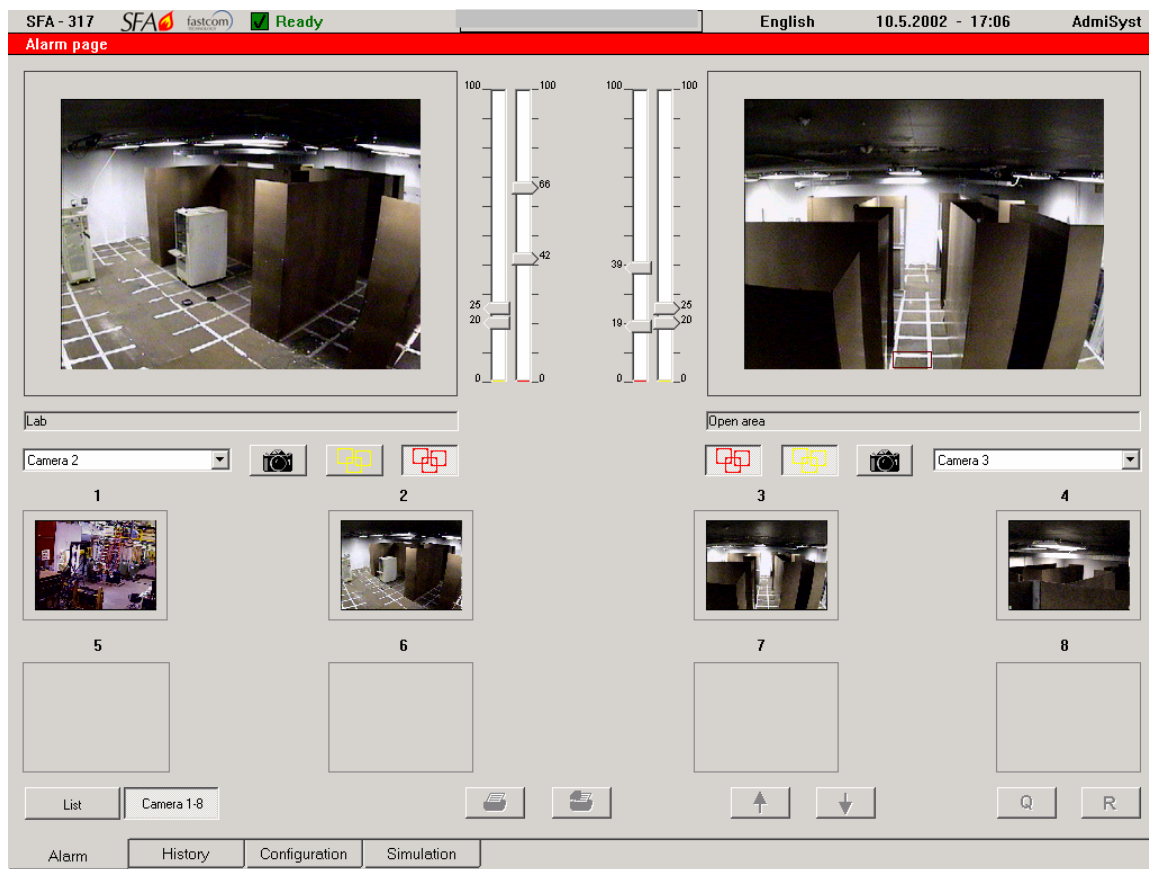


**Fig. 5 – Example of active monitoring display of the SFA graphical user interface**

and supervisory events are logged in a history file.  All alarms and pre-alarm events include a snapshot image.  All displays and images are in color.  The resolution of the SFA video display images is quite good (see Figs. 2-4 for examples).

8

### 4.3    Test Sources

The detection systems were exposed to varying fire and nuisance scenarios intended to be representative of shipboard conditions on DDG51 class ships.  Selection of sources was based in part on previous Navy work which evaluated the development of a multi-criteria fire detection system [3-7].  Tables 3 and 4 respectively present the fire and nuisance sources that were used in this test series.

**Table 3. – Fire Sources**

| No. | Fire Source ID | Description |
|---|---|---|
| 1 | Smoldering Bag of Trash | One bag 60 x 57.5 cm, 32.2 L, 15µm (24 x 23 in., 7-10 gal, 0.6 mil) filled with ordinary trash obtained from the office (printer paper, paper towels, plastic, mailing packs, envelopes).  One cartridge heater (Ogden model MWEJ05J1870, 700 W) energized at 120 VAC was located beneath the closed bag, on top of a piece of gypsum board. |
| 2 | Smoldering Cable Bundle | Bundle of cable consisting of 5 pieces, each one foot in length (Monroe Cable Co., LSTSGU-9, M24643/16-03UN  XLPOLYO).  One 500 W cartridge heater (Vulcan, TB507A) placed in the middle of the bundle energized at 84 VAC (70% of 120 V max).  These sources typically transitioned to flaming fires. |
| 3 | Smoldering Wire | Two pieces of 1 m long wire were powered in parallel at 6 VAC (with no current limit) for 1 minute.  The wire was constructed of 10, 0.1 mm strands, insulated with PVC to a radial thickness of 0.3 mm, with a cross-sectional area of $0.078 \text{ mm}^2$.  The test follows British Standard BS6266 [8]. |
| 4 | Smoldering Printed Circuit Board | Test replicates fires in circuit boards.  A FR-4 substrate board was energized at 6 V, 8.5 amps to produce smoldering substrate and a traveling arc between two 50 mil wide copper tracks, spaced 50 mil apart.  See References [4 and 9] for details. |
| 5 | Smoldering Laundry | Three miscellaneous pieces of clothing (cotton) were loosely piled.  One 500 W cartridge heater (Vulcan, TB507A) powered at 120 VAC was placed in the middle of the pile. |
| 6 | Smoldering Mattress and Bedding | One 0.3 x 0.3 m (12 x 12 in.) section of Navy mattress (MIL-M-18351F(SH), 11.4 cm thick Safeguard polychloroprene foam core covered with a fire retardant cotton ticking) was under a loose pile of bedding, including one polyester batting, quilted mattress pad (Volunteer Blind Industries, GS-07F-14865, DDD-P-56E), one sheet (Federal Specification DDD-S-281) and one brown bed spread (Fed Spec DDD-B-151) (each 0.6 x 0.6 m).  One cartridge heater (Ogden model MWEJ05J1870, 700 W) energized at 120 VAC was located between the bedding and the mattress.  This test transitioned |

| No. | Fire Source ID | Description |
|-----|----------------|-------------|
|     |                | to flaming at 366 s. |
| 7 | Smoldering Computer Monitor | A 15 inch standard monitor was exposed to an internal heat source. One 500 W cartridge heater (Vulcan, TB507A) was inserted into a 1.6 cm (0.625 in.) hole at the bottom corner of the monitor (either front of back). The cartridge heater was energized to 80 to 100% of the 120 VAC supply, depending on the test. |
| 8 | Lactose/Chlorate | A mixture of 1.5 g potassium chlorate and 1.5 g of lactose were mixed thoroughly and formed in a pile. The mixture was lit with a butane lighter. The test follows British Standard BS6266 [8]. The mixture burned vigorously with a small flame and produced a gray smoke that looks and smells like that produced by ordinary matches. |
| 9 | Smoke pellet | One 13 g smoke pellet (ph Smoke Products Ltd.) lit with a butane lighter produced a white smoke for approximately 60 seconds. |
| 10 | Flaming Trash Can | One 60 x 57.5 cm, 32.2 L, 15µm (24 x 23 in., 7-10 gal, 0.6 mil) bag was filled with ordinary trash obtained from the office (printer paper, paper towels, paper cups) and placed in a metal trash can. The open bag of trash was lit at the top with a butane lighter. |
| 11 | Flaming Mattress and Bedding | A butane lighter was used to ignite the top bedding material in the corner of the mattress and bedding setup described in Item 6. |
| 12 | Heptane Pan | 100 to 250 ml of heptane was poured into various square pans, sizes included 0.127 x 0.127 m (5 x 5 in.), 0.152 x 0.152 m (6 x 6 in.), and 0.17 x 0.17 m (6.7 x 6.7 in.). The amount of fuel added produced an approximate burn time of 4.5 minutes. |
| 13 | JP-5 Pan | 75 ml of JP-5 fuel was burned in a 0.127 x 0.127 m (5 x 5 in.) pan. |
| 14 | Cardboard Box | Test 6 – A single, closed 0.26 x 0.26 x 0.1m (10 x 10 x 4 in.) box filled with four loosely crumpled, 0.6 x 0.8 m sheets of brown paper was lit on a bottom corner for about 15 s with a butane lighter – after approximately a minute, the externally flaming box transitioned to primarily an internally smoldering fire. Test 20 – A two tiered stack of four boxes (about the size above) were loosely filled with brown paper and positioned with a 2.5 cm flue space between the two stacks. A butane lighter was used to light a bottom corner of a box in the flue space so that flames propagated up the flue space and involved both boxes. |

Though the fire sources have been generally classified as smoldering and flaming fires, multiple sources were actually both. For example, most of the computer monitor fires and the electrical cable bundle and mattress and bedding fires started as smoldering sources and transitioned to flaming sources. Similarly, the first box fire was initiated as a flaming fire but transitioned to a smoldering source. For this analysis, the sources have been classified by their initial burning condition.

**Table 4. – Nuisance Sources**

| No. | Nuisance Source ID | Description |
|---|---|---|
| 1 | Cigarette Smoke | Two smokers in the space, each smoking a single cigarette |
| 2 | Aerosol Deodorant | Five second spray intervals at multiple locations in the test space. Test 38 – America's Choice Spray Deodorant (regular scent). |
| | | Test 45 – Old Spice High Endurance Anti-perspirant and deodorant (pure sport). The Old Spice produced a larger volume of visible aerosol. |
| 3 | Toaster: Overdone Toast | White bread toasted at the darkest setting for two cycles. |
| 4 | Welding | Welding of two pieces of steel using an arc welder |
| 5 | Torch Cut Painted Steel | Cutting 0.6 cm (1/4") thick, painted angle iron with an oxyacetylene torch. |
| 6 | Grinding Unpainted Steel | Grinding metal with a 3 ½" power hand grinder |
| 7 | Cutting Unpainted Steel | Cutting 1/8" angle iron with a 14" metal cut off saw |
| 8 | People Working on Ladders | Working on ladders in the overhead, in view of the cameras. |
| 9 | Waving a Towel | Waving of a towel as to shake clean (~ 5 min.) in view of Camera 2. |
| 10 | Turning Lights On and Off | Cycle the lights in the open area of the test space (i.e., the left two vertical rows of lights in Fig. 1) on and off (10 second duration each cycle for two minutes). |
| 11 | Sunlight | Open outside rollup delivery door to let sunlight shine in through the open test compartment door (D1) and observation windows. |

The sources were initiated at various locations throughout the test space. The locations are identified by number in Fig. 6. Multiple locations were used along with the various sources to create a broad range of conditions to test the detection systems in the compartment.

## 4.4    Test Procedure

The general test procedure was to assure that all equipment was operational, that all system clocks were synchronized, and then to execute the test, ventilate the compartment and continue with the next test. The procedure included a check and establishment of a clean baseline for all systems between tests. For each test, the primary data acquisition system was started and allowed to run for a minimum of 90 seconds. After the background data was collected, the source was initiated and allowed to continue until fully consumed or until all systems were in alarm or showed no change in detection due to quasi-steady state conditions.
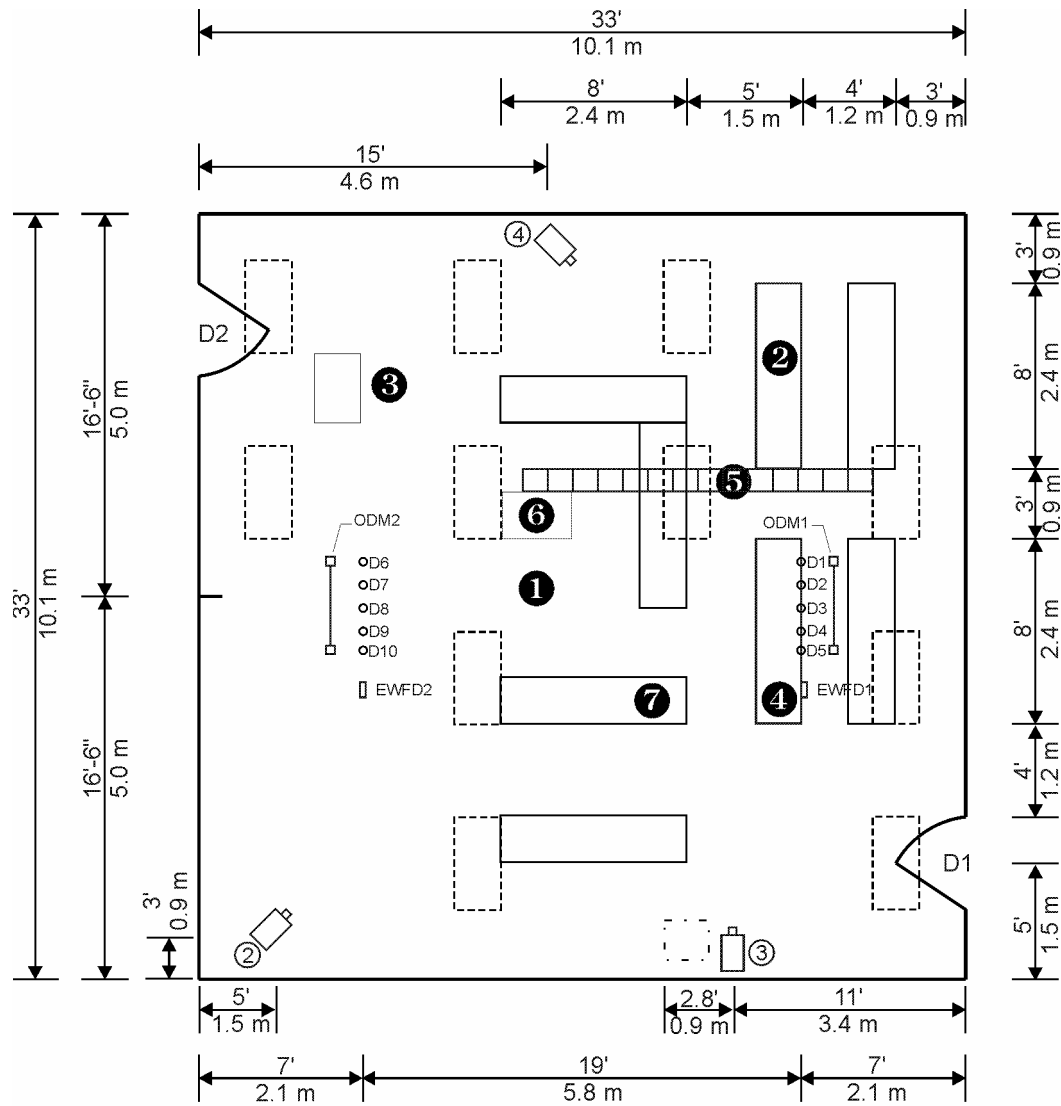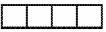
**Fig. 6. – Source locations**

Legend:

- Cabinet/bunks (2' x 8' x 8' high)
- Overhead lighting (2' x 4')
- Cable tray in overhead
- Exhaust vent in overhead (1.8' x 1.8')
- Camera (8" below overhead)
- Smoke detector (1' spacing)
- ODM (1' from detectors)

**5.0    RESULTS**

Table 5 presents a summary of the tests conducted.  The Table provides the test name, the source type, source description and source location.  If an elevated location designation, such as bunk or desk, is not noted, then the source was located on the deck (i.e., the floor).  The corresponding heights for the bunk, desk, table and cabinet are 1.2 m (47 in.), 0.66 m (26 in.), 0.66 m and 1.6 m (63 in.), respectively.  Appendix A and B present summary tables sorted by source type and source location, respectively.  Appendix C includes selected photographs of sources.

Tests ADC048 to ADC059 were conducted after a modification was made to one of the video-based detection systems in an effort to reduce false alarms due to people moving and working in the test space.  The modification consisted of a standard system parameter adjustment that can be set by the user/installer.  Since the last eleven tests were conducted with a slightly different setup, the majority of the analysis below considers only tests ADC001 through ADC047.

Tables 6 to 8 present the alarm times for the video-based detection systems and the standard ionization and photoelectric smoke detectors for tests ADC001 through ADC047, sorted per source type.  The alarm times are presented for the following six detection systems:

- Video-based detection system 1 (VD1)
- Video-based detection system 2 (VD2)
- Simplex ionization system detectors (S.I.)
- Simplex photoelectric system detectors (S.P.)
- Notifier ionization system detectors (N.I.)
- Notifier photoelectric system detectors (N.P.)

A detection system consisted of all of the devices within the test space.  For example, each video-based detection system was considered to have alarmed if an alarm was generated from any of the three camera views.  Similarly, a point-type smoke detection system consisted of the two smoke detectors (e.g., both Notifier ionization) that were located on opposite sides of the test space.  Table 6 presents the individual alarm times for each camera of both of the video-based fire detection systems followed by the system response, which was the fastest response time of the three camera alarms.  Table 7 presents both the individual detector alarm times and the system alarm times for the Simplex ionization and the Simplex photoelectric smoke detectors.  Similarly, Table 8 presents the results for the Notifier ionization and photoelectric detectors.  The alarm times are reported with respect to the initiation of the source.

The video-based detection systems produced alarms per the settings established by the manufacturers.  These alarm conditions were not changed during tests ADC001 to ADC047. The Simplex and Notifier detection systems were evaluated at typical alarm sensitivity levels. The ionization smoke detectors were evaluated at the manufacturers factory default setting (1.3%/ft for Simplex and 1.8%/ft for Notifier).  The photoelectric smoke detectors were

evaluated at a common alarm level of 2.4%/ft, (Simplex default was 2.5, and the Notifier default was 2.12). Overall, the smoke detection system results in Tables 7 and 8 represent a benchmark of the state-of-the-art point-type detection technology operating at normal settings.

Tables 7 and 8 also provide two columns following the system response times that present the time differences between the point-type smoke detection system alarm and both video-based fire detection system alarms. For example, column 8 in Table 7 shows the time difference between the Simplex ion detector alarm ($t_{S.I.}$) and the alarm time for video-based detection system 1 ($t_{VD1}$). If both the point- and the video-detection systems alarmed, a positive difference indicates that the video-based detection system responded faster. The time differences that appear in the darker cells in the Table are for tests in which one of the systems did not respond. For these cases, a negative or positive alarm difference is dependent on which system did not respond.

**Table 5. – Summary of Tests Conducted**

| Test | Source Type[1] | Source | Source Location |
|---|---|---|---|
| ADC001 | S | Smoldering bag of trash | 1 |
| ADC002 | F | Mattress and bedding | 2 on bunk |
| ADC003 | N | Sunlight | Door 1 |
| ADC004 | S | Smoke pellet | 2 |
| ADC005 | F | Trash can | 3 |
| ADC006 | F/S | Cardboard box | 1 |
| ADC007 | N | Welding | 1 |
| ADC008 | S/F | Mattress and bedding | 2 on bunk |
| ADC009 | S | Smoke pellet | 4 |
| ADC010 | F | Heptane pan - 0.17 m | 3 |
| ADC011 | S/F | Cable bundle | 5 |
| ADC012 | S | Computer monitor | 3 on desk |
| ADC013 | S | Lactose/chlorate | 2 |
| ADC014 | S/F | Cable bundle | 5 |
| ADC015 | S/F | Computer monitor | 3 on desk |
| ADC016 | S | Printed wire board | 6 on cabinet |
| ADC017 | S | Smoldering wire | 7 |
| ADC018 | F | Trash can | 3 |
| ADC019 | S | Smoldering laundry | 2 on bunk |
| ADC020 | F | Cardboard boxes | 1 |
| ADC021 | S | Smoke pellet | 3 |
| ADC022 | S | Smoke pellet | 1 |
| ADC023 | S | Smoke pellet | 7 |
| ADC024 | F | Mattress and bedding | 1 |
| ADC025 | F | Trash can | 1 |

| Test | Source Type[1] | Source | Source Location |
|---|---|---|---|
| ADC026 | F | Heptane pan - 0.17 m | 3 |
| ADC027 | F | Heptane pan - 0.15 m | 3 |
| ADC028 | F | Heptane pan - 0.13 m | 3 |
| ADC029 | F | Heptane pan - 0.13 m | 3 |
| ADC030 | F | Heptane pan - 0.13 m | 1 |
| ADC031 | S | Lactose/Chlorate | 1 |
| ADC032 | S/F | Computer Monitor | 1 on desk |
| ADC033 | S | Smoldering wire | 6 on cabinet |
| ADC034 | S/F | Cable bundle | 6 on cabinet |
| ADC035 | S | Cable bundle | 6 on cabinet |
| ADC036 | N | Cutting unpainted steel | 1 |
| ADC037 | N | Grinding unpainted steel | 1 |
| ADC038 | N | Aerosol deodorant | all |
| ADC039 | N | Toaster: overdone toast | 6 on cabinet |
| ADC040 | N | Toaster: overdone toast | 6 on cabinet |
| ADC041 | N | Waving of a towel | 1 |
| ADC042 | N | Turning lights on and off | Open area (~ 1 and 3) |
| ADC043 | N | People working on ladders | At cable tray (~5 and 6) |
| ADC044 | N | People smoking | Open area (~ 1 and 3) |
| ADC045 | N | Aerosol deodorant (dry) | all |
| ADC046 | N | Torch cut painted steel | 1 on table |
| ADC047 | N | Torch cut painted steel | 1 on table |
| ADC048 | N | Single worker on ladder | 5 |
| ADC049 | N | Turning lights on and off | Open area (~ 1 and 3) |
| ADC050 | N | Worker on ladder (light blue shirt) | 5 |
| ADC051 | N | Worker on ladder (dark gray shirt) | 5 |
| ADC052 | N | Worker on ladder (white shirt) | 5 |
| ADC053 | N | Worker on ladder (light gray shirt) | 5 |
| ADC054 | S | Electrical cable | 6 on cabinet |
| ADC055 | S | Smoke pellet | 1 on table |
| ADC056 | S | Smoke pellet | 7 |
| ADC057 | S | Lactose/Chlorate | 1 on table |
| ADC058 | S | Lactose/Chlorate | 2 |
| ADC059 | F | JP5 pan fire | 1 |

[1] F=Flaming, S=Smoldering, F/S=Transitioned from Flaming to Smoldering, S/F=Transitioned from Smoldering to Flaming, N=Nuisance

**Table 6. – Alarm Response Times for the Two Video-Based Fire Detection Systems**

| Test | Source Type[1] | Source | Source Location | VD1 Alarm Times (Sec)[2] | | | | VD2 Alarm Times (Sec) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Camera 2 | Camera 3 | Camera 4 | System | Camera 2 | Camera 3 | Camera 4 | System |
| ADC006 | F/S | Cardboard box | 1 | 362 | 263 | 226 | 226 | 214 | 269 | 277 | 214 |
| ADC020 | F | Cardboard boxes | 1 | | | 164 | 164 | 124 | 186 | | 124 |
| ADC010 | F | Heptane pan - 0.17 m | 3 | | | | | | | | |
| ADC026 | F | Heptane pan - 0.17 m | 3 | | | | | | 31 | | 31 |
| ADC027 | F | Heptane pan - 0.15 m | 3 | | | | | | | | |
| ADC028 | F | Heptane pan - 0.13 m | 3 | | | | | | | | |
| ADC029 | F | Heptane pan - 0.13 m | 3 | 188 | 247 | | 188 | | | | |
| ADC030 | F | Heptane pan - 0.13 m | 1 | | 212 | 171 | 171 | | | | |
| ADC002 | F | Mattress and bedding | 2 on bunk | 142 | 117 | | 117 | 162 | 24 | | 24 |
| ADC024 | F | Mattress and bedding | 1 | 106 | | | 106 | 78 | | | 78 |
| ADC005 | F | Trash can | 3 | 263 | | 167 | 167 | 42 | 61 | 236 | 42 |
| ADC018 | F | Trash can | 3 | | 469 | 380 | 380 | 405 | 738 | 585 | 405 |
| ADC025 | F | Trash can | 1 | 107 | 121 | 91 | 91 | 83 | 108 | 148 | 83 |
| ADC013 | S | Lactose/chlorate | 2 | | | 24 | 24 | 37 | 35 | 20 | 20 |
| ADC031 | S | Lactose/Chlorate | 1 | 38 | 65 | 41 | 38 | 28 | 47 | 41 | 28 |
| ADC016 | S | Printed wire board | 6 on cabinet | | | 417 | 417 | 956 | | 487 | 487 |
| ADC004 | S | Smoke pellet | 2 | 132 | 105 | 97 | 97 | 119 | 55 | 86 | 55 |
| ADC009 | S | Smoke pellet | 4 | | 33 | 43 | 33 | 48 | 28 | 25 | 25 |
| ADC021 | S | Smoke pellet | 3 | 167 | | 56 | 56 | 30 | 199 | 51 | 30 |
| ADC022 | S | Smoke pellet | 1 | 46 | 52 | 57 | 46 | 34 | 69 | 56 | 34 |
| ADC023 | S | Smoke pellet | 7 | | 35 | | 35 | 30 | 30 | 31 | 30 |
| ADC001 | S | Smoldering bag of trash | 1 | 675 | | 245 | 245 | 174 | 684 | | 174 |
| ADC019 | S | Smoldering laundry | 2 on bunk | 389 | 162 | | 162 | 353 | 184 | 705 | 184 |
| ADC017 | S | Smoldering wire | 7 | | | 49 | 49 | | | | |
| ADC033 | S | Smoldering wire | 6 on cabinet | | | 49 | 49 | 12 | 17 | | 12 |
| ADC011 | S/F | Cable bundle | 5 | 680 | | 314 | 314 | 379 | 447 | 252 | 252 |
| ADC014 | S/F | Cable bundle | 5 | 735 | | 200 | 200 | 685 | | | 685 |
| ADC034 | S/F | Cable bundle | 6 on cabinet | 224 | 327 | 170 | 170 | 227 | 227 | 159 | 159 |
| ADC035 | S | Cable bundle | 6 on cabinet | 532 | | 288 | 288 | 500 | 304 | 322 | 304 |
| ADC012 | S | Computer monitor | 3 on desk | | | 193 | 193 | 194 | 239 | 343 | 194 |
| ADC015 | S/F | Computer monitor | 3 on desk | | 601 | 506 | 506 | 495 | 599 | 515 | 495 |
| ADC032 | S/F | Computer Monitor | 1 on desk | | | 249 | 249 | 124 | 283 | 238 | 124 |
| ADC008 | S/F | Mattress and bedding | 2 on bunk | 370 | | 178 | 178 | 286 | 334 | 358 | 286 |
| ADC038 | N | Aerosol deodorant | all | | | | | | 111 | | 111 |
| ADC045 | N | Aerosol deodorant) | all | 3 | | 58 | 3 | 1 | 63 | 182 | 1 |
| ADC044 | N | People smoking | Open area (~ 1 and 3) | | | | | | | | |
| ADC039 | N | Toaster: overdone toast | 6 on cabinet | 578 | | 345 | 345 | 413 | 512 | 350 | 350 |

| Test | Source Type[1] | Source | Source Location | VD1 Alarm Times (Sec)[2] | | | | VD2 Alarm Times (Sec) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Camera 2 | Camera 3 | Camera 4 | System | Camera 2 | Camera 3 | Camera 4 | System |
| ADC040 | N | Toaster: overdone toast | 6 on cabinet | 446 | | 352 | 352 | | 360 | 354 | 354 |
| ADC046 | N | Torch cut painted steel | 1 on table | | | | 0 | | | | 0 |
| ADC047 | N | Torch cut painted steel | 1 on table | | | | 0 | | | | 0 |
| ADC042 | N | Turning lights on and off | Open area (~ 1 and 3) | | | | 0 | 48 | 46 | | 46 |
| ADC041 | N | Waving of a towel | 1 | | | | 0 | | | | 0 |
| ADC043 | N | People working on ladders | At cable tray (~5 and 6) | | | | 0 | 403 | 398 | 284 | 284 |
| ADC036 | N | Cutting unpainted steel | 1 | | | | 0 | | | | 0 |
| ADC037 | N | Grinding unpainted steel | 1 | | | | 0 | | | | 0 |
| ADC003 | N | Sunlight | Door 1 | | | | 0 | 16 | 16 | 14 | 14 |
| ADC007 | N | Welding | 1 | 43 | | 42 | 42 | | 24 | | 24 |

[1]  F=Flaming, S=Smoldering, F/S=Transitioned from Flaming to Smoldering, S/F=Transitioned from Smoldering to Flaming, N=Nuisance

[2]  Blank entries indicate that there was no alarm.

# Table 7. – Alarm Response Times for the Simplex Ionization and Photoelectric Smoke Detectors

| Test | Source Type[1] | Source | Source Location | Simplex Alarm Times (Sec)[2] | | | | | | | | | |
|------|------|--------|-----------------|------------|------------|--------|------------|------------|------------|------------|--------|------------|------------|
| | | | | D1 - Ion | D6 - Ion | System | Δt (VD1) | Δt (VD2) | D2 - Photo | D7 - Photo | System | Δt (VD1) | Δt (VD2) |
| | | | | 1.3% Obsc/ft | 1.3% Obsc/ft | Simplex Ions | $t_{S.I.}-t_{VD1}$ | $t_{S.I.}-t_{VD2}$ | 2.4% Obsc/ft | 2.4% Obsc/ft | Simplex Photo | $t_{S.P.}-t_{VD1}$ | $t_{S.P.}-t_{VD2}$ |
| ADC006 | F/S | Cardboard box | 1 | 355 | 294 | 294 | 68 | 80 | 302 | 263 | 263 | 37 | 49 |
| ADC020 | F | Cardboard boxes | 1 | 226 | 121 | 121 | -43 | -3 | | | | -164 | -124 |
| ADC010 | F | Heptane pan - 0.17 m | 3 | 56 | 21 | 21 | 21 | 21 | 183 | 231 | 183 | 183 | 183 |
| ADC026 | F | Heptane pan - 0.17 m | 3 | 53 | 26 | 26 | 26 | -5 | 180 | | 180 | 180 | 149 |
| ADC027 | F | Heptane pan - 0.15 m | 3 | 60 | 33 | 33 | 33 | 33 | 257 | | 257 | 257 | 257 |
| ADC028 | F | Heptane pan - 0.13 m | 3 | 72 | 28 | 28 | 28 | 28 | | | | 0 | 0 |
| ADC029 | F | Heptane pan - 0.13 m | 3 | 81 | 37 | 37 | -151 | 37 | | | | -188 | 0 |
| ADC030 | F | Heptane pan - 0.13 m | 1 | 55 | 29 | 29 | -142 | 29 | | | | -171 | 0 |
| ADC002 | F | Mattress and bedding | 2 on bunk | 70 | 145 | 70 | -47 | 46 | 66 | 136 | 66 | -51 | 42 |
| ADC024 | F | Mattress and bedding | 1 | 83 | 56 | 56 | -50 | -22 | 91 | 87 | 87 | -19 | 9 |
| ADC005 | F | Trash can | 3 | 80 | 54 | 54 | -113 | 12 | 269 | 221 | 221 | 54 | 179 |
| ADC018 | F | Trash can | 3 | 175 | 114 | 114 | -266 | -291 | 570 | 421 | 421 | 41 | 16 |
| ADC025 | F | Trash can | 1 | 46 | 33 | 33 | -58 | -50 | 103 | 90 | 90 | -1 | 7 |
| ADC013 | S | Lactose/chlorate | 2 | | | | -24 | -20 | | | | -24 | -20 |
| ADC031 | S | Lactose/chlorate | 1 | | | | -38 | -28 | | | | -38 | -28 |
| ADC016 | S | Printed wire board | 6 on cabinet | | | | -417 | -487 | 1839 | 827 | 827 | 410 | 340 |
| ADC004 | S | Smoke pellet | 2 | | | | -97 | -55 | 881 | | 881 | 784 | 826 |
| ADC009 | S | Smoke pellet | 4 | | | | -33 | -25 | 112 | | 112 | 79 | 87 |
| ADC021 | S | Smoke pellet | 3 | | | | -56 | -30 | | 126 | 126 | 70 | 96 |
| ADC022 | S | Smoke pellet | 1 | | | | -46 | -34 | | 72 | 72 | 26 | 38 |
| ADC023 | S | Smoke pellet | 7 | | | | -35 | -30 | | | | -35 | -30 |
| ADC001 | S | Smoldering bag of trash | 1 | 733 | 720 | 720 | 475 | 546 | 676 | 370 | 370 | 125 | 196 |
| ADC019 | S | Smoldering laundry | 2 on bunk | | | | -162 | -184 | 765 | 909 | 765 | 603 | 581 |
| ADC017 | S | Smoldering wire | 7 | | | | -49 | 0 | | | | -49 | 0 |
| ADC033 | S | Smoldering wire | 6 on cabinet | | | | -49 | -12 | | | | -49 | -12 |
| ADC011 | S/F | Cable bundle | 5 | | | 0 | -314 | -252 | 210 | 786 | 210 | -104 | -42 |
| ADC014 | S/F | Cable bundle | 5 | Data not available | | | | | Data not available | | | | |
| ADC034 | S/F | Cable bundle | 6 on cabinet | | | 0 | -170 | -159 | 446 | 507 | 446 | 276 | 287 |
| ADC035 | S | Cable bundle | 6 on cabinet | | | 0 | -288 | -304 | | 531 | 531 | 243 | 227 |
| ADC012 | S | Computer monitor | 3 on desk | | | 0 | -193 | -194 | 417 | | 417 | 224 | 223 |
| ADC015 | S/F | Computer monitor | 3 on desk | | 567 | 567 | 61 | 72 | 624 | 550 | 550 | 44 | 55 |
| ADC032 | S/F | Computer Monitor | 1 on desk | 416 | 301 | 301 | 52 | 177 | 319 | 192 | 192 | -57 | 68 |
| ADC008 | S/F | Mattress and bedding | 2 on bunk | 342 | 386 | 342 | 164 | 56 | 298 | 351 | 298 | 120 | 12 |
| ADC038 | N | Aerosol deodorant | All | | | | 0 | -111 | | | | 0 | -111 |

| Test | Source Type[1] | Source | Source Location | Simplex Alarm Times (Sec)[2] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | D1 - Ion | D6 - Ion | System | Δt (VD1) | Δt (VD2) | D2 - Photo | D7 - Photo | System | Δt (VD1) | Δt (VD2) |
| | | | | 1.3% Obsc/ft | 1.3% Obsc/ft | Simplex Ions | $t_{S.I.} - t_{VD1}$ | $t_{S.I.} - t_{VD2}$ | 2.4% Obsc/ft | 2.4% Obsc/ft | Simplex Photo | $t_{S.P.} - t_{VD1}$ | $t_{S.P.} - t_{VD2}$ |
| ADC045 | N | Aerosol deodorant (dry) | All | | | | -3 | -1 | 248 | | 248 | 245 | 247 |
| ADC044 | N | People smoking | Open area (~ 1 and 3) | | | | 0 | 0 | | | | 0 | 0 |
| ADC039 | N | Toaster: overdone toast | 6 on cabinet | | | | -345 | -350 | 243 | 238 | 238 | -107 | -112 |
| ADC040 | N | Toaster: overdone toast | 6 on cabinet | | | | -352 | -354 | | 411 | 411 | 59 | 57 |
| ADC046 | N | Torch cut painted steal | 1 on table | | 70 | 70 | 70 | 70 | | | | 0 | 0 |
| ADC047 | N | Torch cut painted steal | 1 on table | 102 | 216 | 102 | 102 | 102 | | | | 0 | 0 |
| ADC042 | N | Turning lights on and off | Open area (~ 1 and 3) | | | | 0 | -46 | | | | 0 | -46 |
| ADC041 | N | Waving of a towel | 1 | | | | 0 | 0 | | | | 0 | 0 |
| ADC043 | N | People working on ladders | At cable tray (~5 and 6) | | | | 0 | -284 | | | | 0 | -284 |
| ADC036 | N | Cutting unpainted steel | 1 | | | | 0 | 0 | | | | 0 | 0 |
| ADC037 | N | Grinding unpainted steel | 1 | | | | 0 | 0 | | | | 0 | 0 |
| ADC003 | N | Sunlight | Door 1 | | | | 0 | -14 | | | | 0 | -14 |
| ADC007 | N | Welding | 1 | | 143 | 143 | 101 | 119 | | 113 | 113 | 71 | 89 |

[1]  F=Flaming, S=Smoldering, F/S=Transitioned from Flaming to Smoldering, S/F=Transitioned from Smoldering to Flaming,
N=Nuisance

[2]  Blank entries indicate that there was no alarm.

**Table 8. Alarm Response Times for the Notifier Ionization and Photoelectric Smoke Detectors**

| Test | Source Type[1] | Source | Source Location | Notifier Alarm Times (sec)[2] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | D5 - Ion 1.8% Obsc/ft | D10 - Ion 1.8% Obsc/ft | System Notifier Ion | Δt (VD1) $t_{N.I.}- t_{VD1}$ | Δt (VD2) $t_{N.I.}- t_{VD2}$ | D3 - Photo 2.4% Obsc/ft | D8 - Photo 2.4% Obsc/ft | System Notifier Photo | Δt (VD1) $t_{N.P.}- t_{VD1}$ | Δt (VD2) $t_{N.P.}- t_{VD2}$ |
| ADC006 | F/S | Cardboard box | 1 | 409 | 283 | 283 | 57 | 69 | 331 | 259 | 259 | 33 | 45 |
| ADC020 | F | Cardboard boxes | 1 | 236 | 131 | 131 | -33 | 7 | | | 0 | -164 | -124 |
| ADC010 | F | Heptane pan - 0.17 m | 3 | 82 | 43 | 43 | 43 | 43 | 148 | 214 | 148 | 148 | 148 |
| ADC026 | F | Heptane pan - 0.17 m | 3 | 78 | 45 | 45 | 45 | 14 | 147 | | 147 | 147 | 116 |
| ADC027 | F | Heptane pan - 0.15 m | 3 | 95 | 47 | 47 | 47 | 47 | 194 | | 194 | 194 | 194 |
| ADC028 | F | Heptane pan - 0.13 m | 3 | 190 | 88 | 88 | 88 | 88 | 292 | | 292 | 292 | 292 |
| ADC029 | F | Heptane pan - 0.13 m | 3 | 164 | 68 | 68 | -120 | 68 | | | | -188 | 0 |
| ADC030 | F | Heptane pan - 0.13 m | 1 | 124 | 43 | 43 | -128 | 43 | 202 | | 202 | 31 | 202 |
| ADC002 | F | Mattress and bedding | 2 on bunk | 93 | 138 | 93 | -24 | 69 | 66 | 228 | 66 | -51 | 42 |
| ADC024 | F | Mattress and bedding | 1 | 87 | 60 | 60 | -46 | -18 | 99 | 99 | 99 | -7 | 21 |
| ADC005 | F | Trash can | 3 | 222 | 84 | 84 | -83 | 42 | 273 | 231 | 231 | 64 | 189 |
| ADC018 | F | Trash can | 3 | 194 | 83 | 83 | -297 | -322 | 512 | 362 | 362 | -18 | -43 |
| ADC025 | F | Trash can | 1 | 63 | 45 | 45 | -46 | -38 | 114 | 108 | 108 | 17 | 25 |
| ADC013 | S | Lactose/chlorate | 2 | | | | -24 | -20 | 70 | | 70 | 46 | 50 |
| ADC031 | S | Lactose/chlorate | 1 | | | | -38 | -28 | | 62 | 62 | 24 | 34 |
| ADC016 | S | Printed wire board | 6 on cabinet | | | | -417 | -487 | | | 705 | 705 | 288 | 218 |
| ADC004 | S | Smoke pellet | 2 | | | | -97 | -55 | 781 | | 781 | 684 | 726 |
| ADC009 | S | Smoke pellet | 4 | 87 | | 87 | 54 | 62 | 112 | | 112 | 79 | 87 |
| ADC021 | S | Smoke pellet | 3 | | | | -56 | -30 | | 212 | 212 | 156 | 182 |
| ADC022 | S | Smoke pellet | 1 | | 201 | 201 | 155 | 167 | 270 | 90 | 90 | 44 | 56 |
| ADC023 | S | Smoke pellet | 7 | | | | -35 | -30 | | | | -35 | -30 |
| ADC001 | S | Smoldering bag of trash | 1 | 768 | 744 | 744 | 499 | 570 | 681 | 663 | 663 | 418 | 489 |
| ADC019 | S | Smoldering laundry | 2 on bunk | | 880 | 880 | 718 | 696 | 886 | 664 | 664 | 502 | 480 |
| ADC017 | S | Smoldering wire | 7 | | | | -49 | 0 | | | | -49 | 0 |
| ADC033 | S | Smoldering wire | 6 on cabinet | | | | -49 | -12 | | | | -49 | -12 |
| ADC011 | S/F | Cable bundle | 5 | 625 | | 625 | 311 | 373 | 247 | 679 | 247 | -67 | -5 |
| ADC014 | S/F | Cable bundle | 5 | 521 | | 521 | 321 | -164 | 344 | | 344 | 144 | -341 |
| ADC034 | S/F | Cable bundle | 6 on cabinet | 558 | 477 | 477 | 307 | 318 | 447 | 405 | 405 | 235 | 246 |

| Test | Source Type[1] | Source | Source Location | Notifier Alarm Times (sec)[2] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | D5 - Ion | D10 - Ion | System | $\Delta t$ (VD1) | $\Delta t$ (VD2) | D3 - Photo | D8 - Photo | System | $\Delta t$ (VD1) | $\Delta t$ (VD2) |
| | | | | 1.8% Obsc/ft | 1.8% Obsc/ft | Notifier Ion | $t_{N.I.}- t_{VD1}$ | $t_{N.I.}- t_{VD2}$ | 2.4% Obsc/ft | 2.4% Obsc/ft | Notifier Photo | $t_{N.P.}- t_{VD1}$ | $t_{N.P.}- t_{VD2}$ |
| ADC035 | S | Cable bundle | 6 on cabinet | | | | -288 | -304 | 1012 | 616 | 616 | 328 | 312 |
| ADC012 | S | Computer monitor | 3 on desk | | | | -193 | -194 | | | | -193 | -194 |
| ADC015 | S/F | Computer monitor | 3 on desk | | 586 | 586 | 80 | 91 | 682 | 562 | 562 | 56 | 67 |
| ADC032 | S/F | Computer Monitor | 1 on desk | 407 | 287 | 287 | 38 | 163 | 335 | 203 | 203 | -46 | 79 |
| ADC008 | S/F | Mattress and bedding | 2 on bunk | 363 | 393 | 363 | 185 | 77 | 318 | 378 | 318 | 140 | 32 |
| ADC038 | N | Aerosol deodorant | all | | | | 0 | -111 | | | | 0 | -111 |
| ADC045 | N | Aerosol deodorant (dry) | all | | | | -3 | -1 | | | | -3 | -1 |
| ADC044 | N | People smoking | Open area (~ 1 and 3) | | | | 0 | 0 | | | | 0 | 0 |
| ADC039 | N | Toaster: overdone toast | 6 on cabinet | | 421 | 421 | 76 | 71 | 409 | 403 | 403 | 58 | 53 |
| ADC040 | N | Toaster: overdone toast | 6 on cabinet | | 508 | 508 | 156 | 154 | 424 | 460 | 424 | 72 | 70 |
| ADC046 | N | Torch cut painted steal | 1 on table | 214 | 91 | 91 | 91 | 91 | | | | 0 | 0 |
| ADC047 | N | Torch cut painted steal | 1 on table | 97 | 226 | 97 | 97 | 97 | | | | 0 | 0 |
| ADC042 | N | Turning lights on and off | Open area (~ 1 and 3) | | | | 0 | -46 | | | | 0 | -46 |
| ADC041 | N | Waving of a towel | 1 | | | | 0 | 0 | | | | 0 | 0 |
| ADC043 | N | People working on ladders | At cable tray (~5 and 6) | | | | 0 | -284 | | | | 0 | -284 |
| ADC036 | N | Cutting unpainted steel | 1 | | | | 0 | 0 | | | | 0 | 0 |
| ADC037 | N | Grinding unpainted steel | 1 | | | | 0 | 0 | | | | 0 | 0 |
| ADC003 | N | Sunlight | Door 1 | | | | 0 | -14 | | | | 0 | -14 |
| ADC007 | N | Welding | 1 | | 160 | 160 | 118 | 136 | 271 | 121 | 121 | 79 | 97 |

[1] F=Flaming, S=Smoldering, F/S=Transitioned from Flaming to Smoldering, S/F=Transitioned from Smoldering to Flaming, N=Nuisance

[2] Blank entries indicate that there was no alarm.

## 6.0    ANALYSIS

Based on the system response times presented in Section 5, a general assessment can be made of the performance of the video-based detection systems compared to the point-type smoke detection systems. Table 9 presents the number of tests in which each system alarmed for each source type (flaming fire, smoldering fire and nuisance). Since some of the fire sources are not distinctly smoldering or flaming throughout the whole test, an additional column is added in Table 9 to present results for all fires. The column heading numbers in parentheses indicate the total number of tests for each source type.

**Table 9. – The number of tests in which the detection system alarmed per source type**

|  | Flaming Fires (13) | Smoldering Fires (20) | All Fires (33) | Nuisance Sources (14) |
|---|---|---|---|---|
| **VD1** | 9 | 20 | 29 | 4 |
| **VD2** | 8 | 19 | 27 | 8 |
| **Simplex Ion** | 13 | 4 | 17 | 3 |
| **Simplex Photo** | 9 | 15 | 24 | 4 |
| **Notifier Ion** | 13 | 10 | 23 | 5 |
| **Notifier Photo** | 11 | 16 | 27 | 3 |

The two video-based detection systems had essentially the same performance regarding their ability to detect the small incipient fires used in this test program. The systems detected all the smoldering fires, except one system did not alarm to a smoldering wire test (ADC017), which was less than a 60 s duration of a small quantity of smoke. None of the smoke detectors alarmed to either of the two smoldering wire tests (ADC017 and ADC033), whereas both of the video-based systems alarmed to ADC033 and one of the systems alarmed to ADC017. Table 9 illustrates the fact that the video-based detection systems had a greater sensitivity for the smoldering fires. The point detection systems alarmed for as few as four smoldering tests (Simplex ion) and a maximum of 16 tests (Notifier photo) compared to 19 and 20 for the video-based systems. Out of the nine smoldering sources, the smoke pellet test was conducted five times (25% of the smoldering tests) and proved to be easily detected by the video-based systems. However, this test was a particular problem for the Simplex ion system, which detected none, and to a lesser degree the Notifier ion system which detected two out of the five tests. Excluding the smoke pellet tests does not change the overall results and relative ranking of the systems based on the percent of tests that the systems were able to alarm. The results are proportionally the same for the point detection systems (4, 10, 8, and 12 out of 15 tests, respective to Table 9). Therefore, the results indicate for a range of sources that the video-based detection systems have a better capability of detecting incipient smoldering fires than point smoke detectors.

For the tests conducted, Table 9 indicates that the video-based detection systems detected the same or fewer flaming sources compared to the point smoke detection systems. However, the difference in the number of tests resulting in alarm is much less than that observed for the

smoldering tests.  In addition, 6 of the 13 flaming tests were small heptane pool fires, and the large number of these tests partially skews the conclusions.  The heptane fires burned fairly cleanly with little visible smoke production compared to the other fire sources.  This burning behavior provided a challenge to systems relying on larger, visible particles, such as the video-based and the photoelectric smoke detection systems.  A comparison of Tables 7 and 8 show that a large percentage of the photoelectric detectors did not alarm to the heptane fires, but the ionization detectors did alarm (the ionization units are more sensitive to fires producing smaller particles).  Table 6 shows that the video-based detection systems did not alarm to the heptane fires for most of the camera views.  As a whole system, VD1 only alarmed to two of the six heptane fires, and VD2 only alarmed to one of the six.   Both video-based systems alarmed to every other test with the different flaming sources.  Therefore, these results indicate that the video-based detection systems and the point-type smoke detection systems are able to detect most flaming fires.  However, some fairly clean burning fuels pose a detection problem for the video-based and the photoelectric smoke detection systems.  Additional tests with an expanded range of fuel types and combinations, such as various plastics, would be useful in establishing the limitations of the video-based detection algorithm.

Regarding the number of tests causing alarms, Table 9 shows that all of the smoke detection systems, except VD2, performed comparably when exposed to potential nuisance sources.  VD2 showed a higher susceptibility to alarm to changes in light (e.g., turning lights on and off and sudden flooding of sunlight) and object motion, particularly people moving about the space.  VD1 did not alarm to any of the change in light and motion sources.  The following sources caused alarms for both video-based systems: an aerosol deodorant spray, overdone toast and welding.  These sources also caused nuisance alarms for some of the ion and photo smoke detection systems.  Overall, these results indicate that the video-based detection systems can provide equivalent nuisance source immunity compared to point-type smoke detectors.  The advantage that the video-based detection system provides is a video image of the space.  This allows personnel to quickly assess the alarm condition to provide another level of screening before personnel are unnecessarily dispatched to check the space.  Considering this advantageous feature, the video-based detection systems can potentially provide better nuisance alarm immunity than point detection systems, but would require human intervention/decisions.

For the case of VD2, which did have more nuisance alarms, the manufacturer stated after the tests that the nuisances related to light and people moving could be affectively addressed by optimizing the system setup using the standard adjustable parameters.  As noted earlier because of time and logistical constraints, the manufacturers were not allowed to make adjustments to the systems after the tests had started.  In a typical installation, there would be an initial trial period after which the system is readjusted to deal with any issues.  Tests ADC048 to ADC059 were conducted after a modification was made to VD2 in an effort to reduce false alarms due to people moving and working in the test space.  The modification consisted of a standard system parameter adjustment that can be set by the user/installer.  The limited results in these tests indicated that the nuisance immunity improved with a small decline in sensitivity to fires.  Similar to other fire detection systems, there is a trade-off between greater sensitivity for early fire detection and susceptibility to nuisance alarms.  However, there were other settings that could have been

modified in the setup to optimize the nuisance immunity while minimizing any loss in fire sensitivity. However, the limited scope of this initial evaluation did not allow these setups to be evaluated.

Figs. 6 and 7 present charts of the percent of tests in which the video-based detection systems alarmed faster compared to the ionization detection systems and the photoelectric detection systems, respectively. The bar graph labels along the bottom indicate which video based system and point-type smoke detection system are being compared (S is for Simplex and N is for Notifier). The comparisons include all of the tests. Therefore, it must be realized that the results can be influenced by a group of tests that did not result in alarms for a particular detection system. For example, the flaming fire tests results are partly skewed by the large percentage of heptane tests in which the video-based systems did not alarm at all. Similarly, the ionization detectors did not respond to many of the smoke pellet tests. Despite these considerations, the graphs are able to provide a gross assessment of the relative sensitivity of the video-based and point-type smoke detection systems.

Fig. 7 shows that the video-based systems were primarily slower than the ionization detectors for flaming fires but were nearly always faster for smoldering fires, alarming faster in 89 to 100 percent of the tests. The effect of fire type is not as important when the video-based system is compared to the photoelectric detectors (see Fig. 8). The video-based systems were approximately equally as fast as the photoelectric detectors for flaming fires, alarming faster in 46 to 69 percent of the tests. The video-based systems alarm faster than the photoelectric detectors in the majority of the smoldering tests (ranging from 79 to 95% ).

A more detailed analysis of the difference in alarm times can be obtained from Tables 7 and 8 by comparing the alarm times for individual tests in which both the video-based system and the point detection system alarmed (i.e., the entries in the Δt columns that are not shaded). For the flaming fires, the ionization detection systems typically alarmed faster than the video-based systems by approximately 1 to 2.5 minutes. As shown in Fig. 8, neither the video nor point photoelectric detectors were typically faster for the flaming fires; the difference between the video-based system alarms and the photoelectric detector alarms was generally within one minute. For the smoldering fires, the video-based systems were nearly always faster than the smoke detectors (Figs. 7 and 8). The video-based systems alarmed between approximately 0.5 minutes to over 10 minutes faster than the point smoke detectors; the majority of tests were between 1 to 5 minutes.

## 7.0    DISCUSSION

This initial test series provides a basis for moving forward with the use of video-based detection for shipboard applications. The test results indicate that the video-based detection systems using smoke alarm algorithms can provide faster detection than point-type smoke detectors. The main exception is that the video-based systems do not respond to small flaming fires as well as ionization smoke detectors which is a limitation of the algorithm, not the detector.
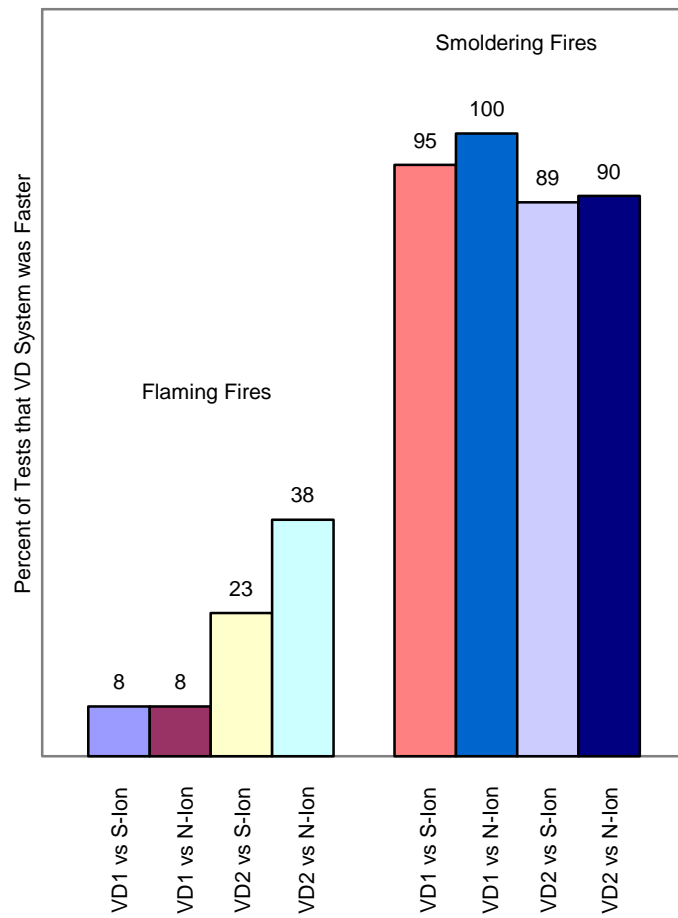
Fig. 7 – The number of tests in which the video detection system was faster than  the specified ionization smoke detection system
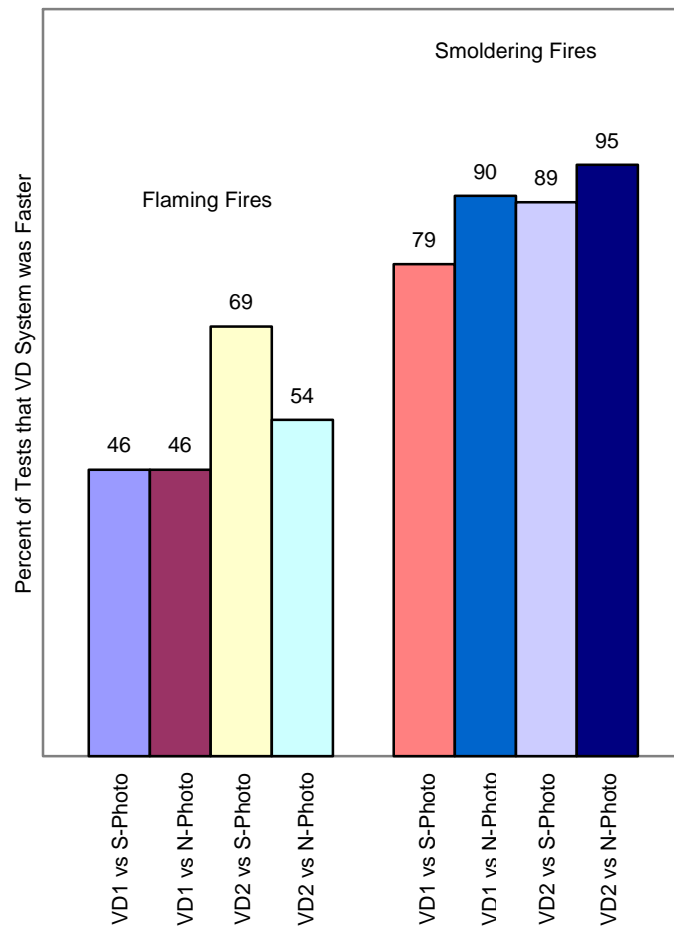
**Fig. 8 – The number of tests in which the video detection system was faster than the specified photoelectric smoke detection system**

For smoldering fires, the video-based detection systems outperformed both the ionization and photoelectric detectors in their ability to detect a larger range of smoldering sources and to alarm faster. For the tests conducted, the video-based systems showed similar overall nuisance alarm immunity.  One of the video-based systems showed a tendency to alarm because of personnel working in the space; however, the manufacturer claims this can be rectified using standard configuration parameters.  We look at this as a limitation of the algorithm and not a weakness of the sensor.

Besides the detection performance summarized above, there are additional advantages of the video-based systems that support their use onboard ship.  A number of these advantages are discussed below.  In addition, areas of concern are also noted.  Since this initial evaluation provides only a limited assessment of the capabilities of these video-based detection systems, issues needing further evaluation are discussed.

Both video-based detection companies have primarily focused on the use of smoke alarm algorithms for fire detection.  Alarm algorithms for the identification of flaming fires are being developed and optimized for both detection systems.  Based on the tests conducted in this study, a preliminary evaluation of one of the flame alarm algorithms indicates that additional fires, such as the small heptane pools, can be detected by the video-based system.  These fires did not produce alarms using the smoke detection algorithms.  Therefore, it is anticipated that future development of flaming fire alarm algorithms could further increase the capabilities of the video-based detection systems to identify a broader range of fires, while minimizing nuisance alarms.  The tests did show that the flame algorithms were more susceptible to motion-type nuisance sources, such as waving a towel.  However, in general the flame detection system was quite immune, alarming to only 2 of 14 nuisance sources that were in the view of the camera.  Although some flaming fires were detected, the evaluation showed that out of 16 flaming fires in the view of Camera 2, the flame algorithm only alarmed for 6 tests (five were heptane fires and one was the flaming cardboard boxes).  Considering that most of the flaming fires were relatively small, the inability to alarm is not necessarily a failure, but rather a measure of the flame size sensitivity of the system.  For example, three sizes of heptane pool fires were conducted.  The flame algorithms were able to detect all sizes.  However, at the smallest size (0.13 x 0.13 m), the system only alarmed for two out of three tests, potentially indicating the lower fire size limit for detection.  The continuing work in FY03 should continue to evaluate and assist in the development of the video-based flame detection alarm algorithms.  Part of this work will define the operating limits (e.g., fire size, type of fires and nuisance alarm immunity) of these flame detection systems.

Video-based detection systems require smoke to enter into the view of a camera.  In very congested compartments with a maze of obstructions, the camera view may be limited to a small volume of the space.  Even with a limited view, the video-based system is able to provide a physically larger range of detection coverage than point-type detectors.  As smoke moves through a space, the point-type detector requires the smoke to reach the exact location of the sensor, typically less than an 80 cc  (5 in$^3$) volume in the overhead.  The video-based system only requires smoke to enter a small area of the volume that the video image covers.  Even in a congested compartment, the camera view will likely be at least several meters across. The video image can also detect smoke from the deck to the overhead; whereas, the point detector will only detect smoke once it reaches the overhead.  Depending on ventilation in the space and the

thermal energy of the source, some fires may result in smoke that stratifies within the space, forming a suspended layer that does not reach the overhead. This phenomenon was observed in this test series. In such cases, the smoke does not get to the point-type smoke detectors, but it is visible in the video images. Although there appears to be a potential coverage advantage in using the video-based systems, a more detailed analysis needs to be performed to demonstrate the limits of the coverage capabilities. The analysis should consider the full range of space sizes and potential obstructions to be encountered. Additional testing should include more complete mockups of obstructions or actual shipboard installations.

The required number of cameras and their locations onboard needs to be assessed within the context of providing specific performance requirements. The detection performance requirements should be established based on the required detection time for specific types and sizes of fires, such that the appropriate manned and/or automatic suppression system response can be effectively implemented. These performance requirements would derive from objectives that specify the acceptable level of hazard or damage from a fire.

The effects of ventilation should be investigated. Ventilation can potentially present a larger problem for point smoke detection technologies by preventing smoke from reaching the detector. Ventilation can also dilute the smoke, which could result in the fire needing to grow bigger or produce greater levels of smoke before the detectors are able to detect it. It is not clear whether certain high ventilation conditions would be sufficiently adverse to render the video-based detection system alarms as inadequately slow for the desired protection objectives. However, it is expected that the video-based detection technology would be less affected by ventilation than would the point smoke detection technologies.

The effects of ventilation need to be considered in light of camera locations and their respective fields of view. This initial test series demonstrates that detection is not always via the video camera that one might expect. For example, Table 10 shows the alarm times for the video-based detection systems for all tests conducted at source location 1, which was directly in the field of view of Camera 2 (see Figs. 2 and 6). Despite the source being directly in the field of view of Camera 2, alarms were first detected, and sometimes only detected, on another camera. For example, the flaming cardboard box fire (ADC020) was not detected by Camera 2 on VD1, but was detected by Camera 4, which viewed the overhead across the tops of the cabinets. The same was true for the smoldering/flaming computer monitor test (ADC032). Both video-based systems had tests in which the movement of smoke first caused alarms at cameras that did not have a direct line of sight of the fire. The detection results for the various camera views were not always consistent between the two video-based systems. Two examples are the flaming

28

**Table 10. – Alarm times for the video-based detection systems for all tests conducted at source location 1**

| Test | Source Type[1] | Source | VD1 Alarm Time (sec) | | | | VD2 Alarm Time (sec) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Camera 2 | Camera 3 | Camera 4 | System | Camera 2 | Camera 3 | Camera 4 | System |
| ADC006 | F/S | Cardboard box | 362 | 263 | 226 | 226 | 214 | 269 | 277 | 214 |
| ADC020 | F | Cardboard boxes | | | 164 | 164 | 124 | 186 | | 124 |
| ADC032 | S/F | Computer Monitor | | | 249 | 249 | 124 | 283 | 238 | 124 |
| ADC036 | N | Cutting unpainted steel | | | | 0 | | | | 0 |
| ADC037 | N | Grinding unpainted steel | | | | 0 | | | | 0 |
| ADC030 | F | Heptane pan - 0.13 m | | 212 | 171 | 171 | | | | 0 |
| ADC059 | F | JP5 pan fire | 81 | 83 | 39 | 39 | | | | 0 |
| ADC031 | S | Lactose/Chlorate | 38 | 65 | 41 | 38 | 28 | 47 | 41 | 28 |
| ADC057 | S | Lactose/Chlorate | | | 4 | 4 | | | 16 | 16 |
| ADC024 | F | Mattress and bedding | 106 | | | 106 | 78 | | | 78 |
| ADC022 | S | Smoke pellet | 46 | 52 | 57 | 46 | 34 | 69 | 56 | 34 |
| ADC055 | S | Smoke pellet | 27 | 52 | 47 | 27 | | 349 | 47 | 47 |
| ADC001 | S | Smoldering bag of trash | 675 | | 245 | 245 | 174 | 684 | | 174 |
| ADC046 | N | Torch cut painted steel | | | | 0 | | | | 0 |
| ADC047 | N | Torch cut painted steel | | | | 0 | | | | 0 |
| ADC025 | F | Trash can | 107 | 121 | 91 | 91 | 83 | 108 | 148 | 83 |
| ADC041 | N | Waving a towel | | | | 0 | | | | 0 |
| ADC007 | N | Welding | 43 | | 42 | 42 | | 24 | | 24 |

[1]  F=Flaming, S=Smoldering, F/S=Transitioned from Flaming to Smoldering, S/F=Transitioned from Smoldering to Flaming, N=Nuisance

29

cardboard boxes test (ADC020) and the welding test (ADC007). In both tests, the VD1 and the VD2 system had alarms on opposite cameras for the same source (i.e., VD1 alarmed on Camera 4 only and VD2 alarmed on Camera 2 and 3 only).

As noted above, developing criteria for locating cameras and establishing fields of view needs to be addressed for the congested spaces found onboard ship. It is not clear at this point if generic installation rules can be developed for a system or if an onsite evaluation of each space would be necessary to develop the system design layout. In addition, a video-based detection system layout would also need to take into account other video system requirements, such as security and personnel surveillance.

The ability to use the basic hardware of the video-based detection system (i.e., the cameras and wiring) for multiple purposes is one of the primary advantages of this system. Adding fire detection on top of a video system that is already onboard inherently minimizes certain installation, maintenance and service costs. A standard fire alarm system using point-type smoke detectors would require independent wiring throughout the ship for all protected spaces. Ship installations of video cameras could use a coax cable run to each camera, as used in these tests, or could use fiber optic or twisted pair.

The testing and maintenance of a point-type fire alarm system is relatively time consuming in that all devices must be serviced. Other than the main computer that operates the video-based detection system, the use of this system does not add additional testing or maintenance of hardware than would already exist for the video system. Future evaluations should include a cost-benefit analysis that includes, installation, maintenance and testing. A cost benefit analysis would need to follow an assessment of the coverage requirements for a video-based system versus a point-detection system.

Another advantage of the video-based detection system is the ability to have live video immediately upon detecting a pre-alarm or an alarm condition. A pre-alarm level can be set at a value that allows personnel to easily view the space and determine whether a false alarm exists or an incipient fire condition is occurring. This pre-alarm would be for a condition that does not pose an unmanageable threat. An alarm value can be set such that personnel are immediately dispatched or an automatic suppression system is activated. Having video of the fire space will allow responding personnel to be more knowledgeable and, thus, adequately prepared for the event upon arrival at the fire scene. The video also provides continuous monitoring of the space so that damage control central does not need to rely upon voice communication for fire scene status reports. A standard fire alarm system does not currently provide any means to assess the state of the fire after the fire is detected.

Future developments in the area of video-based detection hold promise for other shipboard damage control systems to function off of the same video hardware. The video-based image recognition technology has the potential for personnel tracking, flooding detection and physical damage assessment as new event recognition algorithms are developed. Some of this technology is already being implemented, such as personnel tracking through security airlocks. The video-based system can detect the number of people within a space. Development is also underway to provide handheld wireless monitors for the video-based detection system. This

technology would allow personnel to have access to the fire detection system and video anywhere on the ship. The monitor would signal alarm conditions and would automatically bring up the video associated with that alarm. The user would be able to bring up live video of any camera on the system.


## 8.0     CONCLUSIONS AND RECOMMENDATIONS

Computer processing and image analysis technologies have improved significantly to allow the recent development of effective video-based fire detection systems. Currently, smoke detection algorithms are the most mature. Typically, these systems are being designed and used in large facilities, outdoor locations and tunnels. However, the technologies are also expected with some modifications to be effective in smaller, cluttered compartments found on ships. With the move to use onboard video surveillance, there are advantages in using the video images for other functions, such as fire detection. The video-based recognition technology also has future potential for personnel tracking, flooding detection and physical damage assessment onboard ship as more event recognition algorithms are developed.

This work represents the initial evaluation of video-based detection technologies for improved situation awareness and damage control assessment onboard navy ships. Two commercial video-based fire detection systems were evaluated. The evaluation included full-scale testing with a range of flaming and smoldering fire sources and potential nuisance alarm sources. The response of the video-based fire detection systems was benchmarked against standard fire alarm systems using addressable, point-type ionization and photoelectric smoke detectors. The results of the first phase testing and evaluation are presented.

The test results indicate that the video-based detection systems using smoke alarm algorithms can provide comparable to better fire detection than point-type smoke detectors. The main exception is that the video-based systems do not respond to small flaming fires as well as ionization smoke detectors. The video-based systems generally outperformed both ionization and photoelectric smoke detectors in detecting smoldering fires. One video-based system demonstrated comparable nuisance alarm immunity to the point-type smoke detection systems and the other was similar except it sometimes false alarmed to people moving in the space.

Potential advantages include reduced maintenance and testing costs and the reduction of wiring on-board ship. The video-based system provides a higher level of situational awareness than a point-type smoke detection system. The video-based system provides automatic on-scene video to assess conditions prior, during and after personnel intervention or automatic suppression.

The following are future plans:

1. Establish the performance objectives for fire detection to ensure DD(X), CVNX and DDG51 (Phase X) recoverability performance goals with established manning.

2. Establish the performance requirements for video-based detection systems based on the objectives identified in Recommendation 1.

3. Determine the installation requirements for cameras that support effective operation of the system as defined in Recommendations 1 and 2. These requirements need to account for other shipboard camera functions. Future testing should include more complete mockups of obstructions or actual shipboard installations to properly define the limits of coverage capabilities. The analysis should also consider the full range of space sizes and potential obstructions to be encountered.

4. Develop flame alarm algorithms as part of the video-based detection system (current systems have been developed primarily on smoke alarm algorithms).

5. Develop additional algorithms for expanded event detection such as flooding, and damage assessment.

6. Evaluate the effects of ventilation in a space on the performance of video-based detection systems.

7. Evaluate a video-based system on ex-USS *Shadwell*.

8. Perform a cost-benefit analysis of using video-based detection systems versus point-type smoke detection systems. The analysis should consider the hardening aspects of equipment (for both point-type and video-based systems) to meet Navy shock, vibration and EMI requirements.

9. Evaluate a video-based system on an active fleet unit.

## 9.0 REFERENCE

1. Rose-Pehrsson, S.L., Owrutsky, J.C., Gottuk, D.T.; Geiman, J.A., and Williams, F.W., "Advanced Volume Sensor: A Review of the State of the Art," NRL Memorandum Report, NRL Ltr. 6110/204, November 19, 2001.

2. Gottuk, D.T., and McKenna, L.A., "Spot and Aspirated Laser Smoke Detection in Telecommunication Facilities," *Fire Technology*, **38**, 2002, pp. 147-178.

3. Gottuk, D.T., Wright, M.T., Wong, J.T., Pham, H.V., Rose-Pehrsson, S.L., Hart, S.,

Hammond, M., Williams, F.W., Tatem, P.A., and Street, T.A., "Prototype Early Warning Fire Detection System: Test Series 4 Results," NRL/MR/6180-02-8602, February 15, 2002.

4.  Wright, M.T., Gottuk, D.T., Wong, J.T., Pham, H., Rose-Pehrsson, S.L., Hart, S., Hammond, M., Williams, F.W., Tatem, P.A., and Street, T., "Prototype Early Warning Fire Detection System:  Test Series 3 Results," NRL/MR/6180-01-8592, December 19, 2001.

5.  Rose-Pehrsson, S.L., Hart, S.J., Street, T.T., Williams, F.W., Hammond, M.H., Gottuk, D.T., Wright, M.T., and Wong, J.T., "Early Warning Fire Detection System Using a Probabilistic Neural Network," *Fire Technology,* accepted 2002.

6.  Hart, S.J., Hammond, M.H., Wong, J.T., Wright, M.T., Gottuk, D.T, Rose-Pehrsson, S.L., and Williams, F.W., "Real-Time Classification Performance and Failure Mode Analysis of a Physical and Chemical Sensor Array and a Probabilistic Neural Network," *Field Analytical Chemistry and Technology,* **5(5),** 2001, pp.244-258.

7.  Rose-Pehrsson, S.L., Shaffer, R.E., Hart, S.J., Williams, F.W., Gottuk, D.T., Strehlen, B.D., and Hill, S.A., "Multi-Criteria Fire Detection Systems Using a Probabilistic Neural Network," *Sensors and Actuators,* B 69, 2000 pp. 325-335.

8.  British Standards Institute  Standard BS6266, "Code of Practice for Fire Protection for Electronic Data Processing Installations," 1992.

9.  Gottuk, D.T. and McKenna, L.A., "Final Report Response Time Comparison of Spot and Aspirated Laser Smoke Detection Technologies in a Telecommunications Facility," prepared for Notifier/Fire Lite Alarms, Northford, CT, November 10, 1999. (Available at http://haifire.com/download/notifier_tests.pdf )

**APPENDIX A - SUMMARY OF TESTS CONDUCTED SORTED BY SOURCE TYPE**

| Test | Source Type[1] | Source | Source Location |
|------|------|------|------|
| ADC006 | F/S | Cardboard box | 1 |
| ADC020 | F | Cardboard boxes | 1 |
| ADC028 | F | Heptane pan - 0.13 m | 3 |
| ADC029 | F | Heptane pan - 0.13 m | 3 |
| ADC030 | F | Heptane pan - 0.13 m | 1 |
| ADC027 | F | Heptane pan - 0.15 m | 3 |
| ADC026 | F | Heptane pan - 0.17 m | 3 |
| ADC010 | F | Heptane pan - 0.17 m | 3 |
| ADC059 | F | JP5 pan fire | 1 |
| ADC002 | F | Mattress and bedding | 2 on bunk |
| ADC024 | F | Mattress and bedding | 1 |
| ADC005 | F | Trash can | 3 |
| ADC018 | F | Trash can | 3 |
| ADC025 | F | Trash can | 1 |
| ADC013 | S | Lactose/chlorate | 2 |
| ADC031 | S | Lactose/Chlorate | 1 |
| ADC058 | S | Lactose/Chlorate | 2 |
| ADC057 | S | Lactose/Chlorate | 1 on table |
| ADC016 | S | Printed wire board | 6 on cabinet |
| ADC004 | S | Smoke pellet | 2 |
| ADC009 | S | Smoke pellet | 4 |
| ADC021 | S | Smoke pellet | 3 |
| ADC022 | S | Smoke pellet | 1 |
| ADC023 | S | Smoke pellet | 7 |
| ADC055 | S | Smoke pellet | 1 on table |
| ADC056 | S | Smoke pellet | 7 |
| ADC001 | S | Smoldering bag of trash | 1 |
| ADC019 | S | Smoldering laundry | 2 on bunk |
| ADC017 | S | Smoldering wire | 7 |
| ADC033 | S | Smoldering wire | 6 on cabinet |
| ADC011 | S/F | Cable bundle | 5 |
| ADC014 | S/F | Cable bundle | 5 |
| ADC034 | S/F | Cable bundle | 6 on cabinet |
| ADC035 | S | Cable bundle | 6 on cabinet |
| ADC054 | S | Cable bundle | 6 on cabinet |
| ADC012 | S | Computer monitor | 3 on desk |
| ADC015 | S/F | Computer monitor | 3 on desk |

| Test | Source Type[1] | Source | Source Location |
|---|---|---|---|
| ADC032 | S/F | Computer Monitor | 1 on desk |
| ADC008 | S/F | Mattress and bedding | 2 on bunk |
| ADC038 | N | Aerosol deodorant | all |
| ADC045 | N | Aerosol deodorant (dry) | all |
| ADC044 | N | People smoking | Open area (~ 1 and 3) |
| ADC039 | N | Toaster: overdone toast | 6 on cabinet |
| ADC040 | N | Toaster: overdone toast | 6 on cabinet |
| ADC046 | N | Torch cut painted steel | 1 on table |
| ADC047 | N | Torch cut painted steel | 1 on table |
| ADC042 | N | Turning lights on and off | Open area (~ 1 and 3) |
| ADC049 | N | Turning lights on and off | Open area (~ 1 and 3) |
| ADC041 | N | Waving a towel | 1 |
| ADC043 | N | People working on ladders | At cable tray (~5 and 6) |
| ADC048 | N | Person working on ladder | 5 |
| ADC050 | N | Person working on ladder | 5 |
| ADC051 | N | Person working on ladder | 5 |
| ADC052 | N | Person working on ladder | 5 |
| ADC053 | N | Person working on ladder | 5 |
| ADC036 | N | Cutting unpainted steel | 1 |
| ADC037 | N | Grinding unpainted steel | 1 |
| ADC003 | N | Sunlight | Door 1 |
| ADC007 | N | Welding | 1 |

[1] F=Flaming, S=Smoldering, F/S=Transitioned from Flaming to Smoldering, S/F=Transitioned from Smoldering to Flaming, N=Nuisance

**APPENDIX B - SUMMARY OF TESTS CONDUCTED SORTED BY SOURCE LOCATION**

| Test | Source Type[1] | Source | Source Location |
|---|---|---|---|
| ADC006 | F/S | Cardboard box | 1 |
| ADC020 | F | Cardboard boxes | 1 |
| ADC032 | S/F | Computer Monitor | 1 on desk |
| ADC036 | N | Cutting unpainted steel | 1 |
| ADC037 | N | Grinding unpainted steel | 1 |
| ADC030 | F | Heptane pan - 0.13 m | 1 |
| ADC059 | F | JP5 pan fire | 1 |
| ADC031 | S | Lactose/Chlorate | 1 |
| ADC057 | S | Lactose/Chlorate | 1 on table |
| ADC024 | F | Mattress and bedding | 1 |
| ADC022 | S | Smoke pellet | 1 |
| ADC055 | S | Smoke pellet | 1 on table |
| ADC001 | S | Smoldering bag of trash | 1 |
| ADC046 | N | Torch cut painted steel | 1 on table |
| ADC047 | N | Torch cut painted steel | 1 on table |
| ADC025 | F | Trash can | 1 |
| ADC041 | N | Waving a towel | 1 |
| ADC007 | N | Welding | 1 |
| ADC013 | S | Lactose/chlorate | 2 |
| ADC058 | S | Lactose/Chlorate | 2 |
| ADC002 | F | Mattress and bedding | 2 on bunk |
| ADC008 | S/F | Mattress and bedding | 2 on bunk |
| ADC019 | S | Smoldering laundry | 2 on bunk |
| ADC004 | S | Smoke pellet | 2 |
| ADC012 | S | Computer monitor | 3 on desk |
| ADC015 | S/F | Computer monitor | 3 on desk |
| ADC028 | F | Heptane pan - 0.13 m | 3 |
| ADC029 | F | Heptane pan - 0.13 m | 3 |
| ADC027 | F | Heptane pan - 0.15 m | 3 |
| ADC026 | F | Heptane pan - 0.17 m | 3 |
| ADC010 | F | Heptane pan - 0.17 m | 3 |
| ADC021 | S | Smoke pellet | 3 |
| ADC005 | F | Trash can | 3 |
| ADC018 | F | Trash can | 3 |
| ADC009 | S | Smoke pellet | 4 |
| ADC011 | S/F | Cable bundle | 5 |

| Test | Source Type[1] | Source | Source Location |
|---|---|---|---|
| ADC014 | S/F | Cable bundle | 5 |
| ADC048 | N | Person working on ladder | 5 |
| ADC050 | N | Person working on ladder | 5 |
| ADC051 | N | Person working on ladder | 5 |
| ADC052 | N | Person working on ladder | 5 |
| ADC053 | N | Person working on ladder | 5 |
| ADC043 | N | People working on ladders | At cable tray (~5 and 6) |
| ADC034 | S/F | Cable bundle | 6 on cabinet |
| ADC035 | S | Cable bundle | 6 on cabinet |
| ADC054 | S | Cable bundle | 6 on cabinet |
| ADC016 | S | Printed wire board | 6 on cabinet |
| ADC033 | S | Smoldering wire | 6 on cabinet |
| ADC039 | N | Toaster: overdone toast | 6 on cabinet |
| ADC040 | N | Toaster: overdone toast | 6 on cabinet |
| ADC023 | S | Smoke pellet | 7 |
| ADC056 | S | Smoke pellet | 7 |
| ADC017 | S | Smoldering wire | 7 |
| ADC038 | N | Aerosol deodorant | all |
| ADC045 | N | Aerosol deodorant (dry) | all |
| ADC003 | N | Sunlight | Door 1 |
| ADC044 | N | People smoking | Open area (~ 1 and 3) |
| ADC042 | N | Turning lights on and off | Open area (~ 1 and 3) |
| ADC049 | N | Turning lights on and off | Open area (~ 1 and 3) |

[1]   F=Flaming, S=Smoldering, F/S=Transitioned from Flaming to Smoldering, S/F=Transitioned from Smoldering to Flaming, N=Nuisance

**APPENDIX C - PHOTOGRAPHS OF SELECTED TESTS**

Photo 1.  Test ADC001 – Smoldering bag of trash

Photo 2.  Test ADC008 – Smoldering/flaming mattress and bedding

Photos 3 and 4.  Test ADC015 – Smoldering/flaming computer monitor

Photos 5 and 6. Test ADC016 – Printed wire board

Photos 7 and 8. Test ADC021 – Smoke pellet

Photos 9 and 10. Test ADC024 – Flaming mattress and bedding

Photos 11 and 12. Test ADC025 – Flaming/smoldering trash can

Photo 13. Test ADC027 – 0.15 x 0.15 m heptane pan fire

Photo 14. Test ADC033 – Smoldering wire

Photo 15. Test ADC034 – Smoldering/flaming cable bundle

Photo 16. Test ADC034 – Smoldering/flaming cable bundle